

## Claims

What is claimed is:

1. A solder composition, comprising a solder alloy,  
wherein the alloy is substantially free of lead,  
wherein the alloy includes tin (Sn), silver (Ag), and copper (Cu),  
wherein the tin has a weight percent concentration in the alloy of at least about 90%,  
wherein the silver has a weight percent concentration of X in the alloy,  
wherein X is sufficiently small that formation of  $\text{Ag}_3\text{Sn}$  plates is substantially suppressed  
when the alloy in a liquefied state is being solidified by being cooled at to a lower temperature at  
which the solid Sn phase is nucleated,  
wherein the lower temperature corresponds to an undercooling  $\delta T$  relative to the eutectic  
melting temperature of the alloy, and  
wherein the copper has a weight percent concentration in the alloy not exceeding about  
1.5%.

2. The composition of claim 1, wherein X has a predetermined value based on X being  
sufficiently small that formation of said  $\text{Ag}_3\text{Sn}$  plates is substantially suppressed during said  
cooling of said alloy in said liquefied state.

1 3. The composition of claim 1, wherein X does not exceed  $X_{MAX}$ , and wherein  $X_{MAX}$  is the  
2 maximum silver weight percent concentration in the liquefied alloy at which  $Ag_3Sn$  plates are  
3 thermodynamically barred from being formed in the liquefied alloy during said cooling of the  
4 liquefied alloy.

1 4. The composition of claim 3, wherein  $X_{MAX}$  is a function of  $\delta T$ , said function being derived  
2 from a ternary phase diagram and associated thermodynamic data relating to a ternary mixture of  
Sn, Ag, and Cu.

1 5. The composition of claim 1, wherein the copper weight percent concentration in the liquefied  
2 alloy is sufficiently small that the pasty range of the liquefied alloy does not exceed about 10 °C.

1 6. The composition of claim 1, wherein the copper weight percent concentration in the liquefied  
2 alloy does not exceed about 0.9%.

1 7. The composition of claim 1, wherein the alloy further includes a substance that suppresses tin  
2 pest formation in the solidified alloy.

1 8. The composition of claim 7, wherein the substance comprises bismuth, and wherein the  
2 bismuth has a weight percent concentration of at least 0.1% in the alloy.

1        9. The composition of claim 1, wherein X does not exceed about 2.8%.

1      10. The composition of claim 1, wherein X is in a range of about 2.6% to about 2.8%.

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1 11. A method for forming an electrical structure, comprising:

2 providing a first substrate and a first solder ball attached to a first electrically conductive  
3 pad that is coupled to the first substrate, wherein the first solder ball comprises a solder alloy,  
4 wherein the alloy is substantially free of lead, wherein the alloy includes tin (Sn), silver (Ag), and  
5 copper (Cu), wherein the tin has a weight percent concentration in the alloy of at least about  
6 90%, and wherein the copper has a weight percent concentration in the alloy not exceeding about  
7 1.5%;

8 providing a second substrate and a second electrically conductive pad coupled to  
9 the second substrate;

10 coupling the first solder ball to the second pad;

11 melting the first solder ball by heating the first solder ball to form a modified solder ball;

12 and

13 solidifying the modified solder ball by cooling the modified solder ball to a lower  
14 temperature at which the solid Sn phase is nucleated, and wherein the lower temperature  
15 corresponds to an undercooling  $\delta T$  relative to the eutectic melting temperature of the alloy,  
16 wherein the solidified modified solder ball is a solder joint that couples the first substrate to the  
17 second substrate, and wherein a silver weight percent concentration  $X_2$  in the modified solder  
18 ball is sufficiently small that formation of  $Ag_3Sn$  plates is substantially suppressed during said  
19 cooling.

1 12. The method of claim 11, wherein providing the first substrate and the first solder ball  
2 comprises selecting a silver weight percent concentration  $X_1$  in the alloy of the first solder ball  
3 such that  $X_2$  is sufficiently small that said formation of the  $Ag_3Sn$  plates is substantially  
4 suppressed during said cooling.

1 13. The method of claim 11, wherein  $X_2$  does not exceed  $X_{MAX}$ , wherein  $X_{MAX}$  is the maximum  
2 silver weight percent concentration in the modified solder ball at which  $Ag_3Sn$  plates are  
thermodynamically barred from being formed in the modified solder ball during said cooling.

1 14. The method of claim 13, further comprising determining  $X_{MAX}$  as a function of  $\delta T$  from a  
2 ternary phase diagram and associated thermodynamic data relating to a ternary mixture of Sn,  
Ag, and Cu.

1 15. The method of claim 11, wherein the first substrate comprises a chip carrier, and wherein the  
2 second substrate comprises a circuit card.

1 16. The method of claim 15, wherein the first solder ball is a ball grid array (BGA) solder ball.

1 17. The method of claim 11, wherein the first substrate comprises a chip, and wherein the second  
2 substrate comprises a chip carrier.

1 18. The method of claim 11, wherein  $X_2$  is in a range of about 2.6% to about 2.8%.

1 19. The method of claim 11, wherein  $X_2$  does not exceed about 2.8%.

1 20. The method of claim 11, wherein the copper weight percent concentration in the modified  
2 solder ball during cooling is sufficiently small that the pasty range of the modified solder ball  
3 during cooling does not exceed about 10 °C.

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21. The method of claim 11, wherein the copper weight percent concentration in the modified  
solder ball does not exceed about 0.9%.

22. The method of claim 11, wherein the second pad is a copper pad.

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23. The method of claim 11, wherein the second pad is a copper pad, and wherein the copper  
2 weight percent concentration in the first solder ball does not exceed about 0.5%.

1 24. The method of claim 11, wherein the second pad is a nickel-gold pad.

1 25. The method of claim 11, wherein the alloy further includes a substance that suppresses tin  
2 pest formation in the alloy.

1 26. The method of claim 11, wherein coupling the first solder ball to the second pad comprises  
2 applying a flux to the second pad and placing the first solder ball in contact with the flux.

1 27. The method of claim 11,  
2 wherein coupling the first solder ball to the second pad comprises applying a solder paste  
3 to the second pad and placing the first solder ball in contact with the solder paste, and  
4 wherein melting the first solder ball comprises melting the first solder ball and the solder  
paste by heating the first solder ball and the solder paste, such that the melted solder paste is  
incorporated into the melted first solder ball to form the modified solder ball, and such that the  
modified solder ball includes the solder paste within the first solder ball.

28. The method of claim 27, wherein the solder paste includes a weight percent silver  $X_p$  that  
exceeds the silver weight percent concentration  $X_1$  in the alloy of the first solder ball, and  
wherein  $X_2 - X_1$  is at least 0.2%.

- 1 29. A method for forming a solder composition, comprising:
- 2 providing a solder alloy, wherein the alloy is substantially free of lead, wherein the alloy
- 3 includes tin (Sn), silver (Ag), and copper (Cu), wherein the tin has a weight percent
- 4 concentration in the alloy of at least about 90%, wherein the silver has a weight percent
- 5 concentration in the alloy not exceeding about 4.0%, and wherein the copper has a weight
- 6 percent concentration in the alloy not exceeding about 1.5%;
- 7 melting the alloy by heating the alloy; and
- 8 solidifying the melted alloy by cooling the melted alloy at a cooling rate that is high
- 9 enough to substantially suppress  $\text{Ag}_3\text{Sn}$  plate formation in the alloy during said cooling.
- 10
- 11 30. The method of claim 29, further comprising, prior to said solidifying, selecting the cooling
- 12 rate that is high enough to substantially suppress said  $\text{Ag}_3\text{Sn}$  plate formation in the alloy.
- 13
- 14 31. The method of claim 29, wherein the cooling rate is at least about 1.2 °C/sec.
- 15
- 16 32. The method of claim 29, wherein the copper weight percent concentration in the melted alloy
- 17 is sufficiently small that the pasty range of the melted alloy does not exceed about 10 °C.
- 18
- 19 33. The method of claim 29, wherein the copper weight percent concentration in the melted alloy
- 20 does not exceed about 0.9%.



1 34. The method of claim 29, wherein the alloy further includes a substance that suppresses tin  
2 pest formation in the solidified alloy.

1 35. The method of claim 34, wherein the substance comprises bismuth, and wherein the bismuth  
2 has a weight percent concentration of at least 0.1% in the alloy.

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1 36. A method for forming an electrical structure, comprising:

2 providing a first substrate and a first solder ball attached to a first electrically conductive  
3 pad that is coupled to the first substrate, wherein the first solder ball comprises a solder alloy,  
4 wherein the alloy is substantially free of lead, wherein the alloy includes tin (Sn), silver (Ag), and  
5 copper (Cu), wherein the tin has a weight percent concentration in the alloy of at least about  
6 90%, wherein the silver has a weight percent concentration in the alloy not exceeding about  
7 4.0%, and wherein the copper has a weight percent concentration in the alloy not exceeding  
8 about 1.5%;

9 providing a second substrate and a second electrically conductive pad coupled to  
10 the second substrate;

11 coupling the first solder ball to the second pad;

12 melting the first solder ball by heating the first solder ball to form a modified solder ball;

13 and

14 solidifying the modified solder ball by cooling the modified solder ball at a cooling rate  
15 that is high enough to substantially suppress  $\text{Ag}_3\text{Sn}$  plate formation in the modified solder ball  
16 during said cooling, wherein the solidified modified solder ball is a solder joint that couples the  
17 first substrate to the second substrate.

1 37. The method of claim 36, further comprising, prior to said solidifying, selecting the cooling  
2 rate that is high enough to substantially suppress said  $\text{Ag}_3\text{Sn}$  plate formation in the modified  
3 solder ball.

1 38. The method of claim 36, wherein the first substrate comprises a chip carrier, and wherein the  
2 second substrate comprises a circuit card.

1 39. The method of claim 38, wherein the first solder ball is a ball grid array (BGA) solder ball.

1 40. The method of claim 36, wherein the first substrate comprises a chip, and wherein the second  
2 substrate comprises a chip carrier.

41. The method of claim 36, wherein the cooling rate is at least about 1.2 °C/sec.

42. The method of claim 36, wherein the copper weight percent concentration in the alloy is  
sufficiently small that the pasty range of the alloy does not exceed about 10 °C.

43. The method of claim 36, wherein the copper weight percent concentration in the alloy does  
not exceed about 0.9%.

44. The method of claim 36, wherein the second pad is a copper pad.

45. The method of claim 36, wherein the second pad is a copper pad, and wherein the copper  
weight percent concentration in the first solder ball does not exceed about 0.5%.

1 46. The method of claim 36, wherein the second pad is a nickel-gold pad.

1 47. The method of claim 36, wherein the alloy further includes a substance that suppresses tin  
2 pest formation in the alloy.

1 48. The method of claim 36, wherein coupling the first solder ball to the second pad comprises  
2 applying a flux to the second pad and placing the first solder ball in contact with the flux.

49. The method of claim 36,

wherein coupling the first solder ball to the second pad comprises applying a solder paste  
to the second pad and placing the first solder ball in contact with the solder paste, and

wherein melting the first solder ball comprises melting the first solder ball and the solder  
paste by heating the first solder ball and the solder paste, such that the melted solder paste is  
incorporated into the melted first solder ball to form the modified solder ball, and such that the  
modified solder ball includes the solder paste within the first solder ball.

1 50. A pre-soldering electrical structure, comprising:

2 a first substrate and a first solder ball attached to a first electrically conductive pad that is  
3 coupled to the first substrate, wherein the first solder ball comprises a solder alloy, wherein the  
4 alloy is substantially free of lead, wherein the alloy includes tin (Sn), silver (Ag), and copper  
5 (Cu), wherein the tin has a weight percent concentration in the alloy of at least about 90%, and  
6 wherein the copper has a weight percent concentration in the alloy not exceeding about 1.5%;

7 a second substrate and a second electrically conductive pad coupled to the second  
8 substrate, wherein the first solder ball is coupled to the second pad, wherein the first solder ball is  
9 adapted to being melted by being heated to form a modified solder ball, wherein the modified  
10 solder ball is adapted to being solidified by being cooled to a lower temperature at which the  
11 solid Sn phase is nucleated, wherein the lower temperature corresponds to an undercooling  $\delta T$   
12 relative to the eutectic melting temperature of the alloy, wherein the solidified modified solder  
13 ball is a solder joint that couples the first substrate to the second substrate, and wherein a silver  
14 weight percent concentration  $X_2$  in the modified solder ball is sufficiently small that formation of  
15  $Ag_3Sn$  plates are substantially suppressed during said cooling.

1 51. The electrical structure of claim 50, wherein the alloy of the first solder ball has a silver  
2 weight percent concentration  $X_1$ , and wherein  $X_1$  has a predetermined value based on  $X_2$  being  
3 sufficiently small that formation of said  $Ag_3Sn$  plates is substantially suppressed during cooling  
4 of said modified solder ball.

1 52. The electrical structure of claim 50, wherein  $X_2$  does not exceed  $X_{MAX}$ , wherein  $X_{MAX}$  is the  
2 maximum silver weight percent concentration in the modified solder ball at which  $Ag_3Sn$  plates  
3 are thermodynamically barred from being formed in the modified solder ball during said cooling.

1 53. The electrical structure of claim 52, wherein  $X_{MAX}$  is a function of  $\delta T$ , said function being  
2 derived from a ternary phase diagram and associated thermodynamic data relating to a ternary  
3 mixture of Sn, Ag, and Cu.

54. The electrical structure of claim 50, wherein the first substrate comprises a chip carrier, and  
wherein the second substrate comprises a circuit card.

55. The electrical structure of claim 54, wherein the first solder ball is a ball grid array (BGA)  
solder ball.

1 56. The electrical structure of claim 50, wherein the first substrate comprises a chip, and wherein  
2 the second substrate comprises a chip carrier.

1 57. The electrical structure of claim 50, wherein  $X_2$  is in a range of about 2.6% to about 2.8%.

1 58. The electrical structure of claim 50, wherein  $X_2$  does not exceed about 2.8%.

1 59. The electrical structure of claim 50, wherein the solder paste includes a weight percent silver  
2  $X_p$  that exceeds  $X_1$ , wherein  $X_1$  is the weight percent silver in the first solder ball, and wherein  $X_2$   
3 -  $X_1$  is at least 0.2%.

1 60. The electrical structure of claim 50, wherein the copper weight percent concentration in the  
2 modified solder ball during cooling is sufficiently small that the pasty range of the modified  
3 solder ball during cooling does not exceed about 10 °C.

61. The electrical structure of claim 50, wherein the copper weight percent concentration in the  
modified solder ball does not exceed about 0.9%.

62. The electrical structure of claim 50, wherein the second pad is a copper pad.

63. The electrical structure of claim 62, wherein the second pad is a copper pad, and wherein the  
2 copper weight percent concentration in the first solder ball does not exceed about 0.5%.

1 64. The electrical structure of claim 50, wherein the second pad is a nickel-gold pad.

1 65. The electrical structure of claim 50, wherein the alloy further includes a substance that  
2 suppresses tin pest formation in the modified solder ball.

1 66. The electrical structure of claim 65, wherein the substance comprises bismuth, and wherein  
2 the bismuth has a weight percent concentration of at least 0.1% in the alloy.

1 67. The electrical structure of claim 50, wherein the first solder ball is coupled to the second pad  
2 by a flux that is applied to the second pad such that the first solder ball is in contact with the flux.

1 68. The electrical structure of claim 50,

wherein the first solder ball is coupled to the second pad by a solder paste that is applied  
to the second pad such that the first solder ball is in contact with the solder paste; and

wherein the first solder ball is adapted to being melted by heating the first solder ball and  
the solder paste, such that the melted solder paste is incorporated into the melted first solder ball  
to form the modified solder ball, and such that the modified solder ball includes the solder paste  
within the first solder ball.



1 69. A post-soldering electrical structure comprising:  
2 a first substrate; and  
3 a second substrate, wherein the first substrate is coupled to the second substrate by a  
4 solder joint, wherein the solder joint comprises an alloy, wherein the alloy is substantially free of  
5 lead, wherein the alloy includes tin (Sn), silver (Ag), and copper (Cu), wherein the tin has a  
6 weight percent concentration in the alloy of at least about 90%, wherein the silver has a weight  
7 percent concentration in the alloy of  $X_2$ , wherein  $X_2$  is sufficiently small that  $Ag_3Sn$  plates are  
8 substantially absent in the solder joint, and wherein the copper has a weight percent  
9 concentration in the alloy not exceeding about 1.5%.

10 70. The electrical structure of claim 69, wherein the solder joint is formed from a first solder ball  
11 having a tin-silver-copper composition in which the silver has a weight percent concentration  $X_1$ ,  
12 wherein  $X_1$  has a predetermined value based on  $X_2$  being sufficiently small that said  $Ag_3Sn$  plates  
13 are substantially absent in the solder joint.

14 71. The electrical structure of claim 69, wherein the first substrate comprises a chip carrier, and  
15 wherein the second substrate comprises a circuit card.

16 72. The electrical structure of claim 71 wherein the solder joint includes a ball grid array (BGA)  
17 solder ball.

1 73. The electrical structure of claim 69, wherein the first substrate comprises a chip, and wherein  
2 the second substrate comprises a chip carrier.

1 74. The electrical structure of claim 69, wherein  $X_2$  is in a range of about 2.6% to about 2.8%.

1 75. The electrical structure of claim 69, wherein  $X_2$  does not exceed about 2.8%.

1 76. The electrical structure of claim 69, wherein the copper weight percent concentration in the  
2 solder joint is sufficiently small that the pasty range of the solder joint does not exceed about 10  
°C.

1 77. The electrical structure of claim 69, wherein the copper weight percent concentration in the  
2 solder joint does not exceed about 0.9%.

1 78. The electrical structure of claim 69, wherein the alloy further includes a substance that  
2 suppresses tin pest formation in the alloy.

1 79. The electrical structure of claim 78, wherein the substance comprises bismuth, and wherein  
2 the bismuth has a weight percent concentration of at least 0.1% in the alloy.